Available online at https://sanad.iau.ir/journal/jonass
Publisher: Maybod Branch, slamic Azad University
Journal of Nature and Spatial Sciences
ISSN: 2783-1604

Assessment of Urban Heat Island Effects in Mashhad and Neishabour-Iran: A MODIS Imagery Approach

Razieh Mirfazlolah [a]*, Sadegh Mokhtarisabet [b]*

[a]*Department of Remote Sensing and GIS,Yazd Branch, Islamic Azad University, Yazd, Iran*
[b]*Department of Remote Sensing and GIS, Yazd Branch, Islamic Azad University, Yazd, Iran*

A R T I C L E I N F O

Research Type:
Case Study

Article history:
Received 09 Mar 2023
Revised 12 Apr 2023
Accepted 20 Jul 2023

Keywords:
Modis;
LST;
Urban Heat Islands;
Goggle Earth Engine;

A B S T R A C T

Background and objective: Urban Heat Island (UHI) effects are critical challenges in rapidly urbanizing cities, impacting local climates and air quality. This study investigates the UHI effect in Mashhad and Neishabour, Iran, utilizing MODIS satellite imagery to assess temperature variations and their correlation with population density, land use changes, and air pollution levels. The objective is to identify spatial distributions of heat islands and provide insights for effective urban planning to mitigate these effects.

Materials and methods: The study delineated the boundaries of Mashhad and Neishabour, establishing a 1-kilometer buffer zone around each city. A total of 1,005 MODIS images from January 1, 2000, to January 1, 2022, were analyzed to estimate both daytime and nighttime surface temperatures. Various maps were produced to visualize temperature distributions, including a comparative analysis of urban and peripheral areas.

Results and conclusion: The findings revealed significant temperature disparities, with urban areas exhibiting higher daytime temperatures compared to their outskirts. The spatial distribution of UHI effects was strongly correlated with population density and land use changes. Additionally, nighttime temperatures indicated less cooling in urban cores, exacerbating UHI effects. The study concludes that incorporating green spaces and sustainable urban design is essential for mitigating UHI impacts. Recommendations for future research include integrating ground-based measurements to enhance the accuracy of satellite data analyses, ultimately contributing to healthier urban environments.

1. Introduction

Urban Heat Island (UHI) refers to a phenomenon where the temperature of a city is significantly higher than its surrounding rural or less developed areas, creating a distinct "heat island." This temperature differential is due to various anthropogenic factors, including increased population density, urbanization, and air pollution, which alter natural landscapes and contribute to excess heat retention in cities (Wang et al., 2021). The UHI effect is a direct result of urbanization, where surfaces

* *Corresponding author.* Tel.: 0098- 9155183906
E-mail address: mmrqmsh61@gmail.com

Peer review under responsibility of Maybod Branch, Islamic Azad University

DOI: https://doi.org/10.30495/jonass.2024.999770

such as asphalt, concrete, and buildings absorb and re-emit more heat compared to natural landscapes. Mashhad, for example, has experienced a temperature rise of 1.6°C since 1980 due to UHI formation, correlating with the city's population growth and increased air pollution (Naserikia et al., 2019).

Currently, around three billion people live in urban areas worldwide, directly facing the challenges posed by UHI, and this number is expected to grow (Huang et al., 2019). Heat emitted from urban structures and industrial activities contributes significantly to UHI formation, and there is a pressing need to address its effects to mitigate health risks and environmental degradation. Not only does UHI cause a horizontal spread of heat within cities, but it also affects the vertical profile, raising temperatures up to 500 meters above urban areas (Singh et al., 2020). For instance, Kuala Lumpur's UHI has resulted in a temperature increase of 6-7°C, with key contributing factors including artificial heat sources such as cooling systems, vehicular traffic, and industrial activity (Elsayed, 2012).

Changes in land use are also key drivers of UHI. The conversion of natural landscapes into urbanized areas increases surface temperatures, with areas of high vegetation cover recording the lowest temperatures (Bighi et al., 2012). In Tehran, for example, the distribution of surface temperatures between 1986 and 2010 has shifted, with the proportion of areas experiencing extreme heat increasing substantially, while cooler areas have diminished (Sadeghinia et al., 2013).

Google Earth Engine (GEE) is a powerful cloud-based platform that facilitates the analysis of large geospatial datasets, including satellite imagery. Its capabilities are particularly beneficial for studying urban heat islands (UHI) and vegetation indices such as the Normalized Difference Vegetation Index (NDVI). By leveraging the extensive MODIS (Moderate Resolution Imaging Spectroradiometer) dataset, GEE allows researchers to efficiently compute surface temperatures and analyze the spatial distribution of UHI. This platform supports real-time data processing and visualization, enabling comprehensive assessments of urban environments and the impacts of land cover changes on temperature variations. The integration of MODIS data in GEE enhances the accuracy of UHI studies, providing crucial insights for urban planning and environmental management (Gorelick et al., 2017).

Satellite imagery has proven to be a valuable tool in estimating surface temperatures and monitoring UHI over time. Technologies such as MODIS, AVHRR, and Landsat satellite data allow researchers to capture spatial temperature variations across urban landscapes (Bokaie et al., 2019). Using algorithms such as those developed by Price and Key, researchers can estimate temperatures from satellite imagery and compare them with ground measurements (Zhou et al., 2018). Among these, Landsat 8 offers a higher resolution, enabling a more accurate estimation of surface temperatures, particularly with the use of thermal bands 10 and 11, where band 11 has proven superior in estimating surface temperature (Cristóbal et al., 2018).

Urban impervious surfaces, such as asphalt and roofs, significantly contribute to UHI by absorbing heat, while green spaces can moderate temperatures by providing cooler microclimates (Cheela et al., 2021). The correlation between land surface temperature (LST) and the Normalized Difference Vegetation Index (NDVI) indicates that green spaces play a critical role in reducing UHI effects. High-resolution infrared remote sensing provides a more detailed understanding of urban heat patterns and helps in devising strategies to combat UHI (Kumar & Shekhar, 2015).

The city of Mashhad, a major urban center and a prominent pilgrimage destination, has faced increasing air pollution and UHI-related challenges in recent years. The correlation between air pollution and UHI intensification in Mashhad suggests that the city's expanding population and industrial development have contributed to worsening environmental conditions. Despite interventions such as switching to cleaner fuels and implementing traffic restrictions, the UHI effect remains a concern, impacting both public health and the preservation of cultural heritage sites.

Objectives

This study aims to investigate the UHI effect in the cities of Mashhad and Neishabour using MODIS satellite imagery and assess the relationship between UHI and urban air pollution. By identifying the spatial distribution of heat islands and their contributing factors, the study seeks to provide insights into how urban planning can mitigate UHI effects.

Hypotheses

- **Hypothesis 1:** The spatial distribution of the Urban Heat Island (UHI) effect in Mashhad and Neishabour is significantly influenced by population density, land use changes, and the presence of vegetation, with areas of higher urbanization exhibiting greater temperature disparities.
- **Hypothesis 2:** The application of MODIS satellite imagery provides accurate and reliable data for detecting and quantifying the UHI effect, thereby facilitating more effective environmental management and informed urban planning strategies.

With these insights, it is hoped that the results of this study can contribute to creating a healthier and more sustainable urban environment in the Razavi Khorasan province, reducing the negative impacts of UHI on both residents and the preservation of the region’s historical and cultural assets.

2. Materials and Methods

2.1. Study Area

The study area includes two major cities in the northeast of Iran. Mashhad and Neishabour, both located in Razavi Khorasan province, each exhibiting unique geographical and climatic characteristics relevant to the study of Urban Heat Island (UHI) effects.

Mashhad is the capital of Razavi Khorasan province and one of Iran’s largest metropolises. With an area of 351 square kilometers, it is located at 36°17'50" N latitude and 59°36'24" E longitude, situated in the valley of the Kashf River, between the Binalud and Hazar Masjid mountains. Mashhad's elevation is 1050 meters above sea level, and the city experiences an average annual rainfall of 22.93 mm, based on data collected between 1966 and 2017. With a population of 3,001,184 according to the 2015 census, Mashhad is a densely populated urban center, prone to significant UHI effects due to its rapid urbanization and industrialization (Rabiei-Dastjerdi et al., 2021; Naserikia et al., 2019). Fig. 1 illustrates the geographical location of Mashhad within Iran.

Neishabour is another key city in Razavi Khorasan province, located approximately 70 kilometers west of Mashhad. Neishabour covers an area of 5805 square kilometers, stretching from 35°34' N to 36°56' N latitude and 58°10' E to 58°62' E longitude (Jafari et al., 2017). It is situated on the eastern edge of the Iranian desert, largely surrounded by plains, with the Binaloud mountain range to the north and east. The city’s geography is defined by high mountain ranges, particularly the Kouh Serkh and Nize Band ranges to the south and the Jogtai highlands to the west. Neishabour’s population stood at 451,780 in 2015, making it the second most populous city in the province and the 29th in the country. The urban core, Neishabour city, had a population of 264,375 during the same census, ranking 31st among Iranian cities in terms of population. This combination of geographic isolation, varied topography, and urban growth makes Neishabour an ideal subject for UHI analysis alongside Mashhad (Jafari et al., 2017).

Both cities represent important case studies for evaluating UHI patterns due to their differing geographic features, population densities, and levels of urban development. The analysis of these areas using MODIS satellite imagery will provide valuable insights into the spatial dynamics of UHI in two distinct urban environments within the same climatic region.

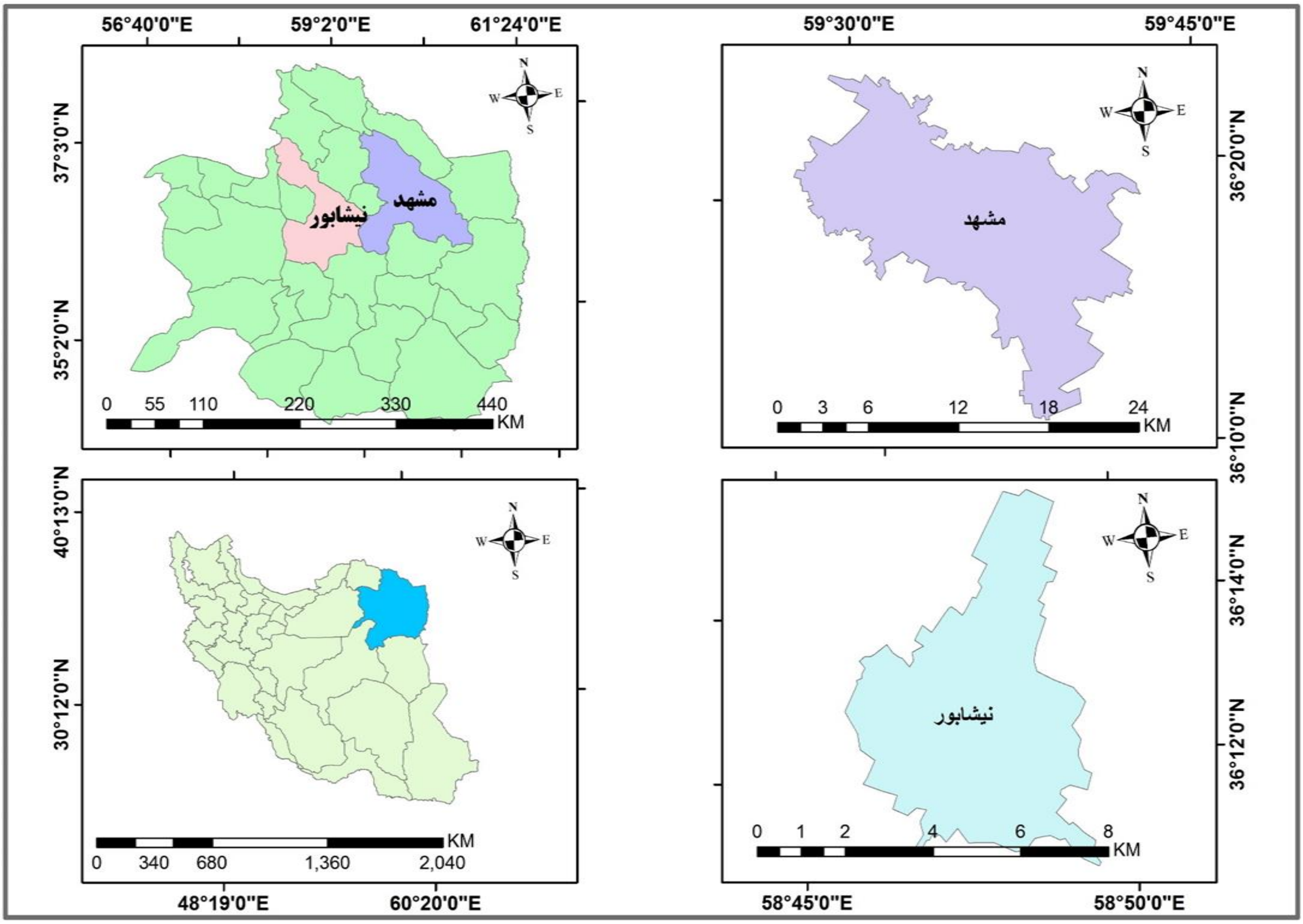


Fig. 1 – Geographical location of the study areas in Iran, highlighting a) Mashhad and b) Neishabour, within the Razavi Khorasan province

2.2. Flowchart of Research Methodology

Before delving into the specific methodologies, a flowchart (Fig. 2) illustrates the step-by-step process followed in this research. This visual representation provides a clear overview of the sequence of tasks undertaken, from data acquisition to analysis and interpretation.

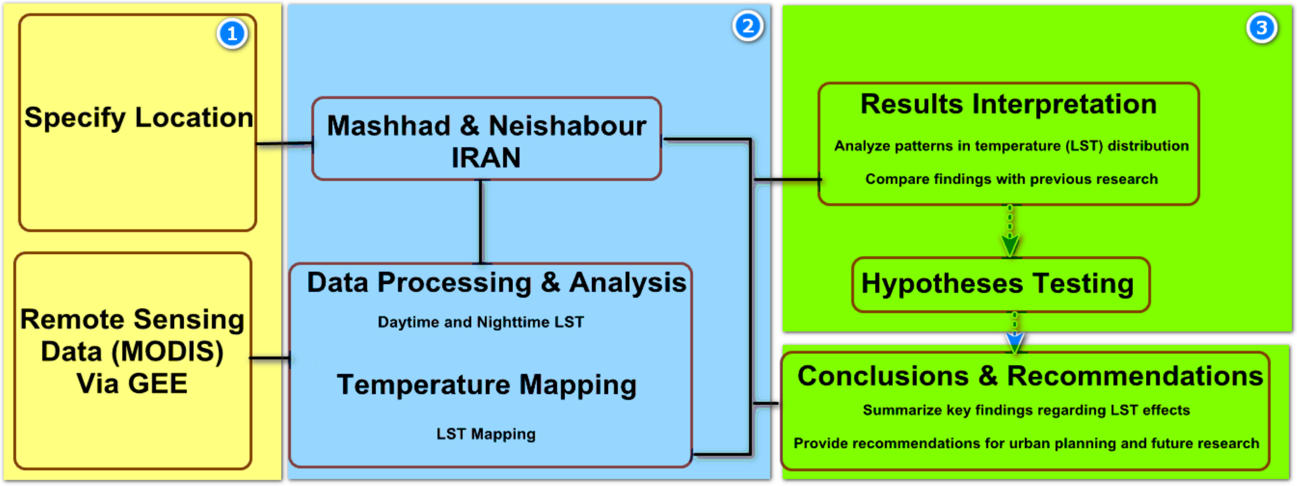


Fig. 2 - Workflow diagram illustrating the step-by-step research process for investigating the LST effect in Mashhad and Neishabour, from defining objectives and selecting study areas to data analysis and publication.

2.3. Data Acquisition

A total of 1005 MODIS satellite images were utilized for this study, covering the period from January 1, 2000, to January 1, 2022. The images used were pre-processed and made available as ready-to-use products, thus eliminating the need for extensive corrections. The MODIS (Moderate Resolution Imaging Spectroradiometer) provides reliable data regarding surface temperatures and other land surface characteristics, making it suitable for UHI studies (Phan & Kappas, 2018).

2.4. Surface Temperature Calculation

To estimate the average land surface temperature (LST) for Mashhad and Neishabour, both day and night temperatures were calculated using the MODIS data. The procedure involved applying specific algorithms that utilize the thermal bands of MODIS imagery, which capture the emitted infrared radiation from the Earth’s surface. This process ensures the differentiation between daytime heating and nighttime cooling, providing a comprehensive understanding of temperature variations.

Daytime and Nighttime LST Estimation: Daytime LST was estimated by analyzing images captured during daylight hours, while nighttime LST was derived from images taken after sunset. The difference between these two temperature readings was computed to generate thermal maps that illustrate the UHI effect.

Map Production: The temperature data were represented spatially through thematic maps created for both cities. These maps provide a visual interpretation of LST variations and highlight areas experiencing significant UHI effects.

2.5. Data Analysis and Interpretation

The processed temperature maps were then analyzed using geospatial analysis techniques to identify patterns and correlations. Statistical methods were employed to examine the relationship between land surface temperature, population density, and land use changes.

Statistical Analysis: Techniques such as correlation analysis and regression modeling were utilized to quantify the relationships among the variables, providing insights into how urbanization and pollution levels affect UHI intensity.

Validation of Results: To ensure the accuracy and reliability of the findings, the estimated temperatures were compared with ground-based temperature measurements and meteorological data where available. This validation process is crucial for assessing the precision of the MODIS-derived temperature estimates.

2.6. Limitations

While the methodology employed in this study is robust, several limitations should be noted. The accuracy of satellite imagery can be affected by atmospheric conditions, and the resolution of MODIS images may not capture microclimatic variations within urban areas. Additionally, data gaps due to cloud cover may impact the consistency of temperature readings.

This research methodology outlines a systematic approach to analyzing the UHI effect in Mashhad and Neishabour. By employing advanced geospatial tools and statistical analysis, this study aims to contribute valuable insights into the dynamics of urban heat islands, informing urban planning and environmental management strategies in northeastern Iran.Distance from Surface Water: Maintaining an adequate distance from rivers, lakes, and other bodies of water is vital to safeguard against potential contamination.

3. Results

3.1 Surface Temperature Estimation

The results of the land surface temperature (LST) estimation for Mashhad and Neishabour were analyzed to assess the extent and intensity of Urban Heat Islands (UHIs) in these cities. The temperature data was visualized in thematic maps, as shown in Fig. 3. The estimated surface temperatures ranged from a minimum of 295 K to a maximum of 312 K (approximately 22°C to 39°C).

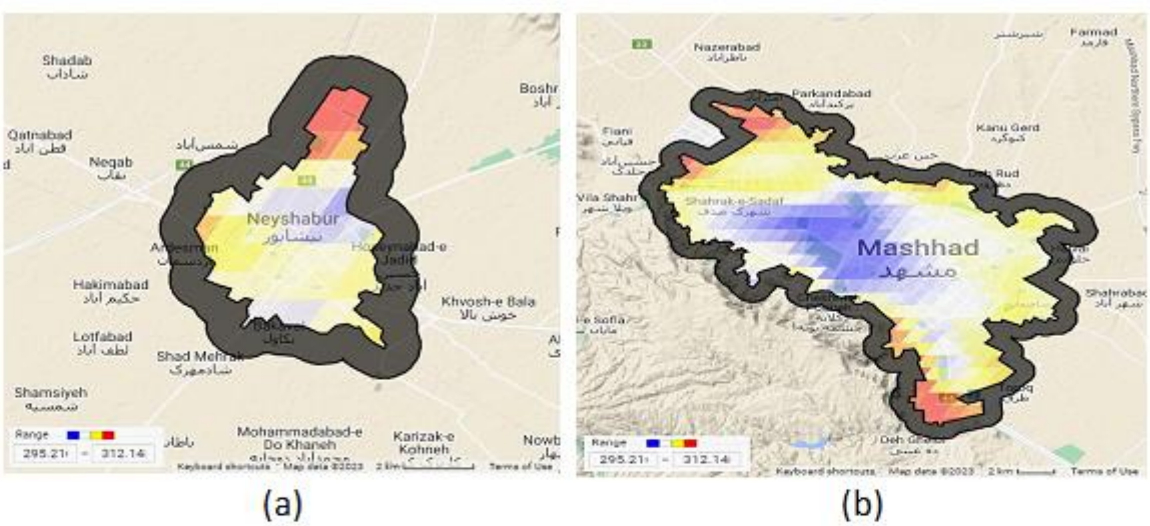


Fig 3 - Daytime Land Surface Temperature (LST) distribution for the period 2000-01-01 to 2022-01-01 in a) Neishabour and b) Mashhad.

3.2. Spatial Distribution of Surface Temperatures

The thematic maps illustrate the spatial distribution of surface temperatures across the two urban areas.

- Mashhad: In Mashhad, the central urban core exhibited the lowest temperatures, represented in blue on the map. These cooler zones likely correspond to areas with higher vegetation cover or less dense construction, providing a microclimate that mitigates extreme heat. In contrast, peripheral areas and densely built environments showed significantly higher temperatures, indicating pronounced UHI effects.
- Neishabour: Similarly, in Neishabour, the central areas displayed lower temperature readings compared to the outskirts. However, the temperature gradient was steeper in Neishabour, suggesting that urbanization has a more pronounced impact on temperature in this city than in Mashhad.

3.3 Analysis of Urban Heat Islands

The differences in temperature readings between the urban cores and surrounding areas reveal the presence and intensity of UHIs. The analysis indicates that:

- The UHI intensity is more significant in Mashhad, where urbanization has accelerated over the past two decades, leading to elevated surface temperatures in areas with limited green space and increased impervious surfaces.
- In Neishabour, while UHI effects are present, they are less severe than in Mashhad. This may be attributed to the relatively lower population density and more balanced urban development patterns.

3.4 Comparative Analysis

To further understand the impact of UHI in these cities, a comparative analysis of temperature fluctuations between day and night was conducted.

- Daytime Temperatures: Daytime surface temperatures in both cities were generally higher, indicating substantial solar heating of urban materials. In Mashhad, peak daytime temperatures were observed in industrial and commercial zones, reflecting the heat generated by human activities.
- Nighttime Temperatures: Nighttime cooling was less pronounced in Mashhad compared to Neishabour, suggesting that built-up areas retain heat more effectively, exacerbating UHI effects. This retention is likely influenced by the materials used in construction, such as asphalt and concrete, which have high thermal mass.

3.5 Implications of Findings

The findings underscore the importance of incorporating urban greening strategies to mitigate UHI effects. Areas with lower temperatures are crucial for maintaining a livable urban environment, especially during extreme heat events.

- Recommendations: The analysis suggests that urban planning in both cities should prioritize the integration of green spaces and sustainable development practices. Strategies such as increasing vegetation cover, implementing green roofs, and enhancing urban ventilation can help alleviate the intensity of UHI.

3.6. Nighttime Surface Temperature Analysis

Fig. 4 presents the estimated nighttime land surface temperatures (LST) for the cities of Mashhad and Neishabour, complementing the daytime temperature data shown in Fig. 3. In this visualization, the color gradient indicates temperature variations, with red representing the highest temperatures and blue representing the lowest.

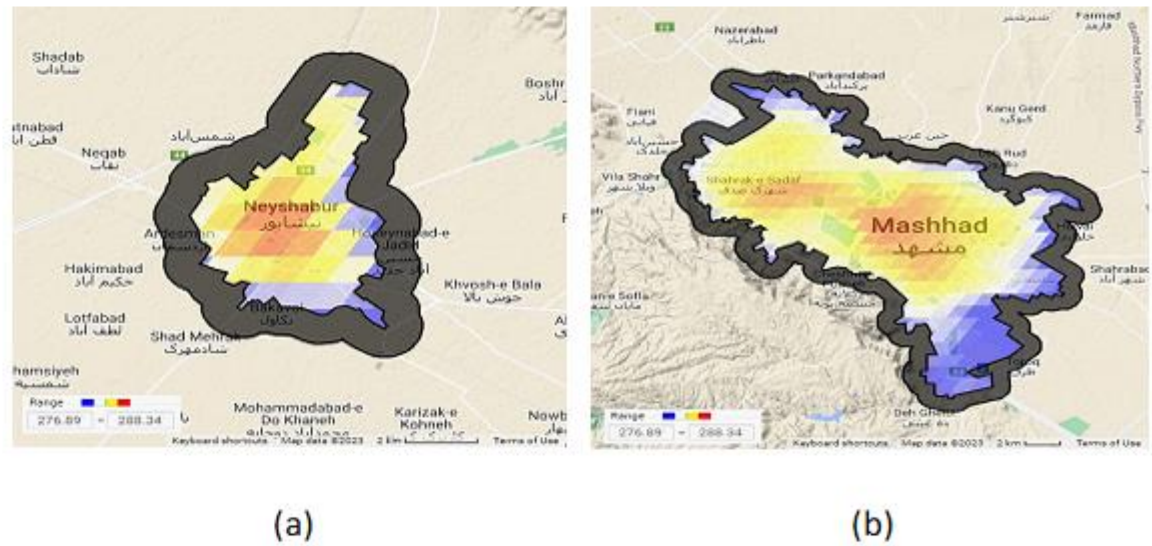


Fig 4 - Nighttime Land Surface Temperature (LST) distribution for the period 2000-01-01 to 2022-01-01 in a) Neishabour and b) Mashhad.

3.6.1. Observations from Nighttime Temperature Data

The analysis of nighttime temperatures reveals several key patterns:

- Urban Core Heat Retention: The highest nighttime temperatures are concentrated in the central urban areas of both Mashhad and Neishabour. This phenomenon is indicative of heat retention in urban environments, where materials such as asphalt and concrete absorb and retain heat throughout the day, releasing it slowly at night. The core areas, characterized by high-density development and limited vegetation, experience reduced cooling compared to their surrounding regions.
- Temperature Variability: In contrast to daytime temperatures, which exhibited a more extensive range, nighttime temperatures show less variability. This suggests that urbanization influences the thermal characteristics of these areas more significantly during the night, leading to a more uniform distribution of heat retention.

3.6.2. Comparative Insights

When comparing the nighttime data with daytime readings, the following insights emerge:

- Greater Temperature Contrast in Urban Areas: The disparity between nighttime and daytime temperatures is notably pronounced in the urban core of Mashhad. While the core retains heat, the surrounding areas benefit from greater cooling due to natural landscapes, which contribute to a more favorable microclimate. In Neishabour, the difference is less stark, suggesting that the urban fabric has not yet reached the same level of density and heat retention as in Mashhad.
- Impact on Urban Comfort: The implications of elevated nighttime temperatures are significant for urban comfort and public health. Prolonged exposure to higher nighttime temperatures can exacerbate heat-related illnesses and discomfort among residents. It highlights the necessity for urban design that encourages cooling, such as increasing green spaces and promoting air circulation.

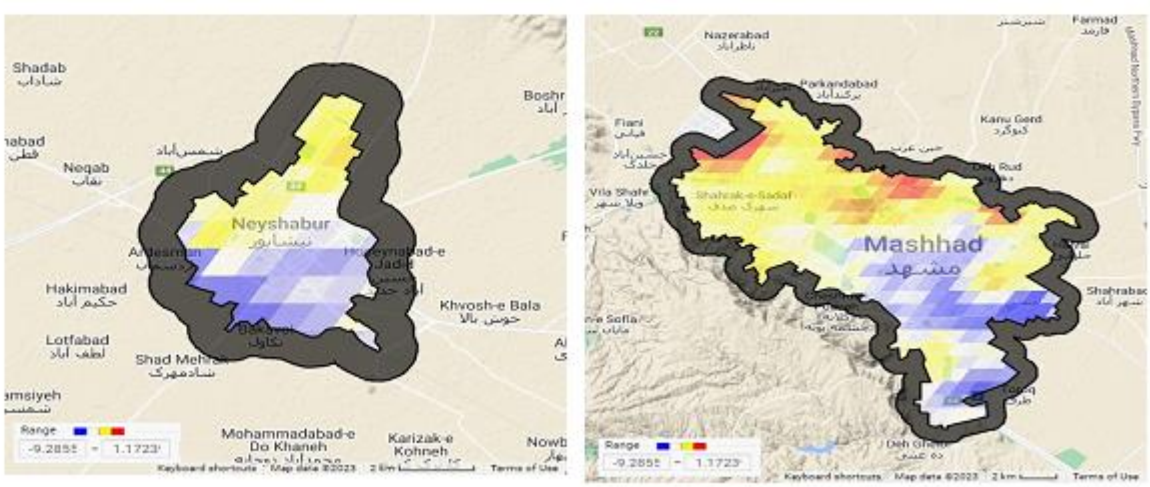
3.6.3. Implications for Urban Planning

The findings from the nighttime temperature analysis have critical implications for urban planning and environmental management:

- Design Strategies: Urban planners should prioritize strategies that enhance nighttime cooling. This could involve implementing green roofs, increasing urban forestry, and creating shaded areas to mitigate heat retention.
- Awareness and Education: Raising awareness among residents about the importance of maintaining green spaces and reducing heat islands can foster community support for urban greening initiatives.

3.7. Temperature Difference Analysis

After generating the average daytime and nighttime temperature maps, we proceed to analyze the temperature difference between these two periods, as illustrated in Fig.5 . The recorded temperature difference in the cities of Mashhad and Neishabour ranges from -9 K to 1 K.



(a) (b)

Fig 5 - Temperature Difference between Day and Night LST from 2000-01-01 to 2022-01-01 in a) Neishabour and b) Mashhad.

3.7.1. Interpretation of Temperature Differences
In the temperature difference map:

- Color Gradient: The lowest temperature differences are indicated in blue, while the highest differences are represented in red. This gradient allows for a visual representation of how temperatures fluctuate between day and night in both cities.
- Understanding Negative Differences: A negative temperature difference (up to -9 K) indicates that nighttime temperatures are significantly lower than daytime temperatures in certain areas. This pattern suggests effective nighttime cooling, which is more pronounced in regions with ample vegetation or less urban development.

3.7.2. Spatial Distribution of Temperature Differences

The analysis reveals distinct spatial patterns in the temperature differences between Mashhad and Neishabour:

- Urban Cores vs. Periphery: In both cities, the urban cores typically show smaller temperature differences, reflected in the blue areas of the map. The limited cooling at night in these densely built environments suggests heat retention due to materials that absorb heat during the day and release it slowly at night.
- Peripheral Areas: Conversely, peripheral areas display a broader range of temperature differences, with more regions showing higher nighttime cooling. This is attributed to the lower density of buildings and greater vegetation cover in these areas, allowing for more effective heat dissipation.

3.7.3. Implications for Urban Heat Management

The findings from the temperature difference analysis have important implications for urban heat management:

- Identifying Hotspots: Areas with minimal temperature differences can be targeted for interventions aimed at reducing heat retention. Strategies may include increasing green cover, implementing reflective materials, and promoting urban design that facilitates airflow.
- Urban Planning Considerations: Understanding where significant temperature differences occur can guide urban planners in developing strategies to improve thermal comfort for residents, particularly during warmer months.

3.8. Analysis of Peripheral Temperature Variations

Following the generation of maps depicting average daytime and nighttime surface temperatures, as well as the differences between them, it becomes imperative to analyze the peripheral areas surrounding Mashhad and Neishabour..

3.8.1. Peripheral Temperature Mapping

Fig. 6 displays the surface temperatures of the outskirts of both Mashhad and Neishabour, using a color gradient to indicate temperature variations. The daytime temperatures in these areas range from 296 K to 306 K (approximately 23°C to 33°C).

- Heat Imbalance: The maps reveal notable heat imbalances across different zones in the periphery. Areas closer to the urban core exhibit higher temperatures, while those further away benefit from cooler conditions. This pattern is typical of urban heat islands, where urban areas absorb and retain heat more effectively than their rural counterparts.

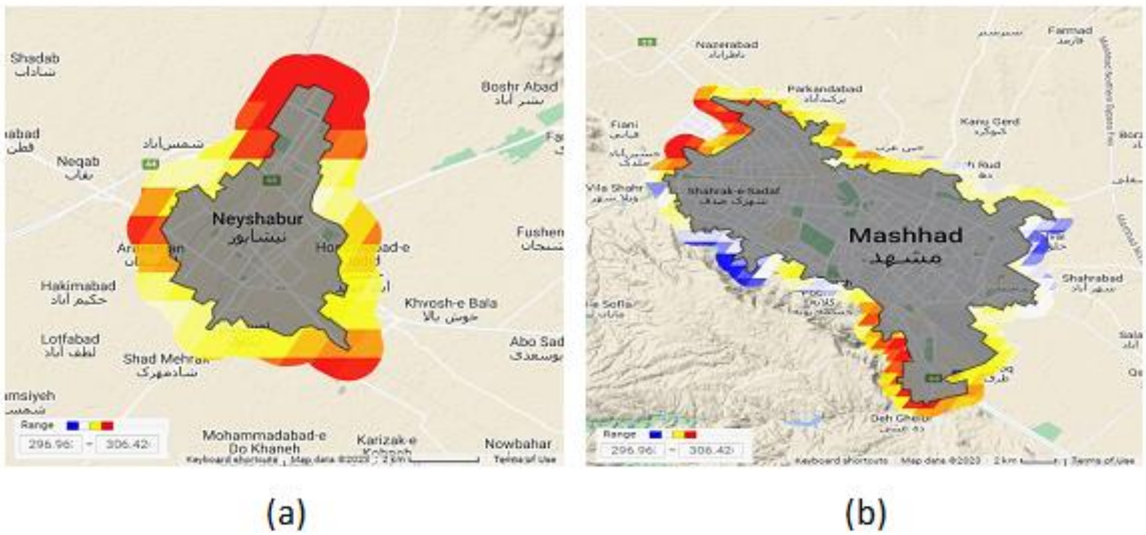


Fig 6 - Daytime Land Surface Temperature (LST) in the Peripheral Areas of a) Neishabour and b) Mashhad from 2000-01-01 to 2022-01-01.

3.8.2 Insights into Temperature Distribution

The temperature variations observed in the peripheral areas can be attributed to several factors:

- Land Use Differences: The contrasting land use between urban and rural settings plays a significant role in temperature disparities. Urbanized areas with impervious surfaces contribute to higher temperatures due to reduced vegetation and increased heat retention. Conversely, agricultural and natural landscapes typically exhibit cooler temperatures, promoting a more favorable thermal environment.
- Impact of Vegetation: The presence of vegetation in peripheral areas significantly influences local microclimates. Areas with dense tree cover or agricultural fields are cooler, highlighting the importance of green spaces in moderating temperatures and enhancing overall urban resilience.

3.8.3 Comparative Analysis with Urban Cores

When comparing the peripheral temperatures with those in the urban cores, the following observations emerge:

- Gradual Temperature Decline: The transition from the urban core to the outskirts reveals a gradual decline in temperature. This gradient underscores the significance of urbanization in contributing to localized heating effects, with cooler temperatures becoming more prominent as one moves away from densely populated areas.
- Potential for Urban Sprawl: The higher temperatures near the urban edges may encourage further urban sprawl, exacerbating UHI effects if not managed properly. Effective urban planning must consider these dynamics to prevent the expansion of heat islands into peripheral regions.

3.8.4 Implications for Urban Development

The analysis of peripheral temperatures has critical implications for urban development strategies:

- Sustainable Land Management: To mitigate heat imbalances, there is a pressing need for sustainable land management practices that prioritize green infrastructure. Initiatives to restore and maintain vegetation in peripheral areas can significantly contribute to temperature regulation.

- Monitoring and Policy Development: Continuous monitoring of temperature variations in both urban and peripheral areas is essential for developing effective policies aimed at reducing UHI effects. Data-driven approaches can help guide land-use planning and inform interventions that enhance urban livability.

3.9. Nighttime Temperature Analysis in Peripheral Areas

Fig.7 presents the nighttime temperatures of Mashhad and Neishabour, revealing a more balanced thermal distribution compared to daytime temperatures. The map illustrates key patterns in temperature variations across the outskirts of both cities.

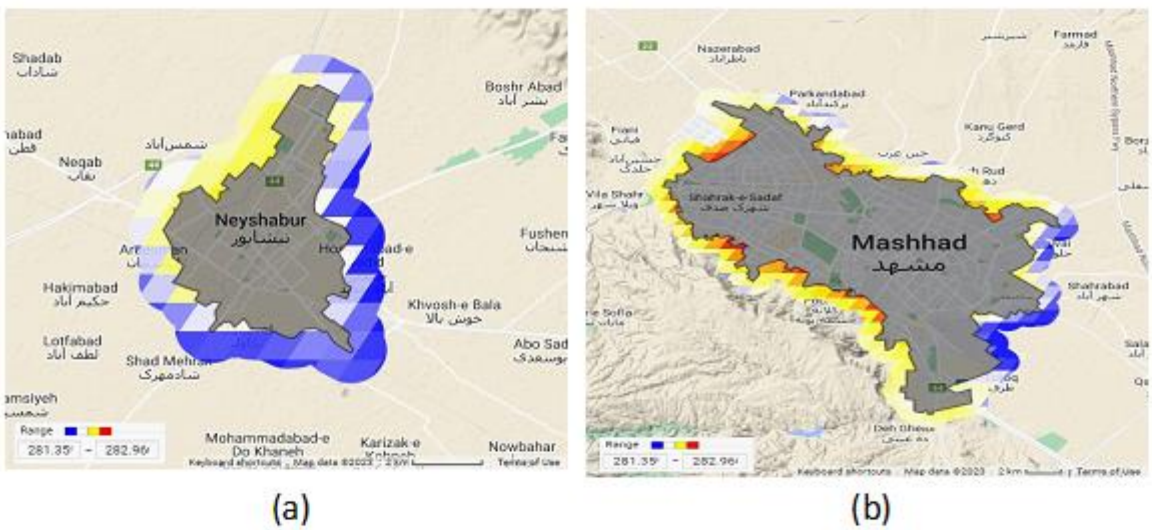


Fig 7: Nighttime Land Surface Temperature (LST) in the Peripheral Areas of a) Neishabour and b) Mashhad from 2000-01-01 to 2022-01-01.

3.9.1 Observations of Nighttime Temperatures

Heat Balance: Unlike the pronounced daytime heat imbalances, the nighttime temperature map shows a more even distribution of temperatures in the periphery. This indicates that cooling processes are more effective during the night, leading to reduced temperature disparities.

- Comparative Temperatures: Notably, the outskirts of Neishabour are consistently colder than those of Mashhad. This difference can be attributed to several factors, including land use, vegetation cover, and urban density. The cooler temperatures in Neishabour's outskirts suggest a less developed urban area, which may allow for more effective nighttime cooling.

3.9.2 Regional Temperature Variations

Eastern vs. Western Half: Within Neishabour, the eastern half exhibits colder temperatures than the western half. This temperature gradient could be influenced by variations in topography, land cover, and possibly wind patterns, which may facilitate better cooling in the eastern regions.

- Mashhad's Southeastern Edge: In Mashhad, the southeastern edge shows lower temperatures compared to other areas. This could be attributed to differences in land use or vegetation, which might mitigate the heat retained in urban areas.

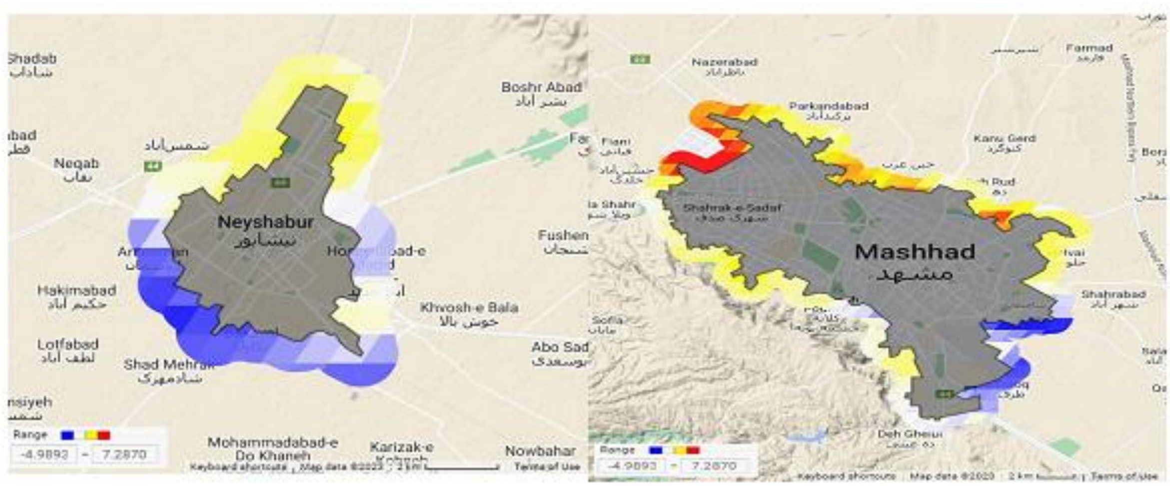
3.9.3 Implications for Urban Planning

The analysis of nighttime temperatures in the periphery has important implications for urban planning and environmental management:

- Urban Heat Island Mitigation: Understanding the temperature dynamics in the outskirts can inform strategies to reduce Urban Heat Island (UHI) effects in Mashhad. Enhancing green spaces and promoting vegetation in hotter areas can facilitate better cooling and improve overall urban resilience.
- Targeted Interventions: Identifying regions with notable temperature differences allows for targeted interventions, such as increasing tree canopies or establishing parks, particularly in the hotter zones of Mashhad.

3.10. Temperature Difference Analysis in Peripheral Areas

The analysis continues with the comparison of Figs 6 and 7, leading to the generation of the temperature difference map for the outskirts of Neishabour and Mashhad (Fig.8). The recorded temperature differences in these areas range from -5 K to 7 K.



(a) (b)

Fig 8 - Temperature Difference (Day-Night) in the Peripheral Areas of a) Neishabour and b) Mashhad from 2000-01-01 to 2022-01-01.

3.10.1. Observations from the Temperature Difference Map

Color Gradient Representation: The temperature difference map highlights variations with negative differences indicated in blue (colder nighttime temperatures) and positive differences in red (warmer daytime temperatures). This visual representation aids in quickly identifying areas with significant temperature fluctuations.

- Northern Mashhad vs. Southern Neishabour: The northern area of Mashhad exhibits the highest temperature difference, indicating that this region retains more heat during the day compared to nighttime cooling. In contrast, the southern outskirts of Neishabour show the lowest temperature differences, suggesting effective cooling processes at night.

3.10.2. Implications for Urban Heat Dynamics

Urban Heat Retention in Mashhad: The higher temperature difference in northern Mashhad underscores the urban heat retention effects commonly associated with densely populated areas. This phenomenon is often exacerbated by impervious surfaces and reduced vegetation, which prevent efficient nighttime cooling.

- Cooling Effect in Neishabour: The lower temperature differences in the southern outskirts of Neishabour highlight the effectiveness of natural landscapes and possibly lower urbanization levels in facilitating cooling. This presents an opportunity for urban planners to consider similar approaches in Mashhad to enhance thermal comfort.

3.10.3. Strategic Urban Planning Recommendations

The insights gained from the temperature difference analysis have several implications for urban planning and development strategies:

- Enhancing Green Spaces: In Mashhad, increasing green spaces, such as parks and urban forests, in areas with high temperature retention could significantly improve nighttime cooling and reduce overall urban temperatures.

- Land Use Planning: For Neishabour, maintaining and promoting natural landscapes can contribute to continued cooling, making it essential to protect these areas from urban encroachment and degradation.

3.11. Temperature Trends in Mashhad and Neishabour

The temperature diagram presented in Fig. 9 illustrates the recorded daily and nighttime temperatures for Mashhad and Neishabour, showcasing two parallel graphs that provide insights into thermal patterns across these urban environments.

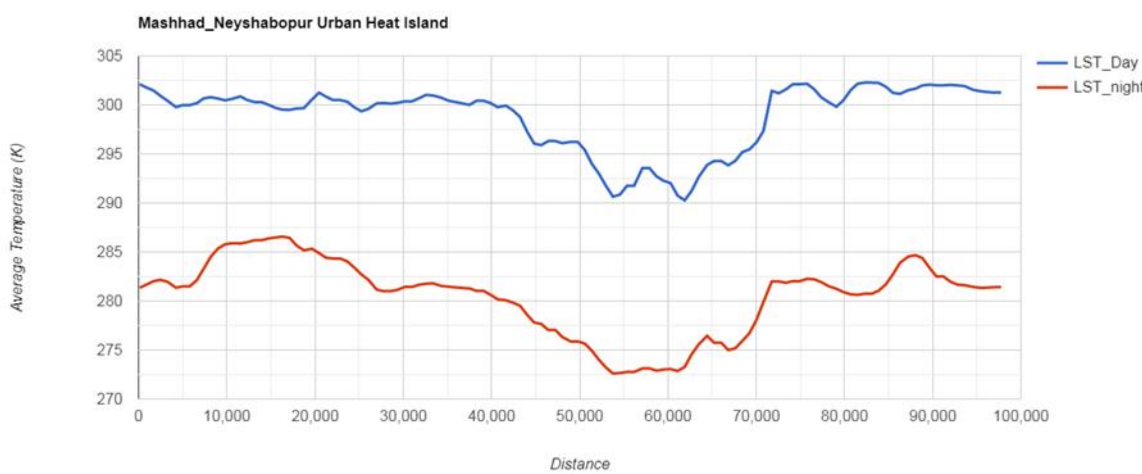


Fig 9 - Graph_LST_Mashahd_neyshabour_2000_01_01 to 2022_01_01

3.11.1. Observations from the Temperature Diagram

- Temperature Peaks and Trends: The graph indicates two distinct peaks, each corresponding to the respective cities. The peaks represent the highest recorded temperatures during the day, while the valleys illustrate nighttime cooling. The descent observed between the two peaks can be attributed to the elevation differences and geographic features, specifically the heights separating the two cities.
- Comparative Analysis of Daily and Night Temperatures: Both temperature curves display a similar trend, suggesting that the thermal behavior of Mashhad and Neishabour is influenced by comparable climatic conditions. However, the daily temperature curve exhibits greater fluctuations compared to the nighttime curve. This variance underscores the intensity of heat retention during the day, likely due to urbanization and built environments.

3.11.2. Implications of Temperature Trends

- Urban Heat Dynamics: The pronounced peaks in daily temperatures indicate that both cities experience significant heat accumulation during the day, which is characteristic of urban heat islands. This phenomenon aligns with previous studies that have documented similar trends in other urban settings (e.g., Solecki et al., 2005).
- Nighttime Cooling Patterns: The relatively stable nighttime temperatures suggest that cooling mechanisms are less pronounced in urban areas compared to their rural counterparts. This reinforces the idea that urbanization can hinder effective cooling at night, further contributing to the UHI effect.

- Impact of Geographic Features: The descent between the peaks points to the influence of geographic barriers, such as elevation, on local temperature variations. This observation highlights the need for localized studies that consider both urban and geographic factors in understanding UHI dynamics.

4. Discussion

This study utilized MODIS satellite imagery to investigate the Urban Heat Island (UHI) effect in Mashhad and Neishabour, focusing on the spatial distribution of heat islands and their relationship with urban air pollution, population density, and land use changes. The methodologies applied, including the analysis of daytime and nighttime temperatures alongside temperature trends, provided a robust framework for understanding UHI dynamics in these cities.

The results corroborate Hypothesis 1, indicating that the spatial distribution of the UHI effect is significantly influenced by population density, land use changes, and the presence of vegetation. Higher temperature disparities were observed in areas with increased urbanization, which aligns with findings from studies in other metropolitan regions. For instance, research by Yang et al. (2019) demonstrated a strong correlation between UHI intensity and urban density in cities like Beijing. Similarly, Zhou and Chen (2018) emphasized the role of land use in shaping temperature profiles, confirming that urbanization exacerbates heat retention.

In Mashhad, the northern regions exhibited the highest temperature differences, suggesting significant heat retention due to dense urban development. Conversely, the cooler outskirts of Neishabour highlight the cooling effects of vegetation and lower urban density. This is consistent with findings from Fu et al. (2022), which showed that increased greenery can mitigate UHI effects, suggesting that integrating green spaces into urban planning could help counteract rising temperatures.

The analysis of temperature trends, particularly from Fig. 8, reveals two distinct peaks in daily temperatures corresponding to each city. The pronounced fluctuations in the daily temperature curve indicate significant heat accumulation during the day, a characteristic of urban heat islands. This observation aligns with research conducted in other urban settings, such as that by Boakye et al. (2024), which also reported pronounced daytime heating effects in densely populated areas.

The relatively stable nighttime temperatures further suggest that urbanization hinders effective cooling, contributing to the UHI effect. The descent between the peaks, reflecting elevation differences, highlights the need for localized studies that consider geographic features in understanding UHI dynamics.

The findings validate Hypothesis 2, confirming that MODIS satellite imagery provides accurate and reliable data for detecting and quantifying UHI effects. This supports previous research, such as that by Phan et al. (2023), which highlighted the effectiveness of MODIS in environmental monitoring. The ability of MODIS data to facilitate fine-scale analysis of surface temperatures makes it an invaluable tool for urban planners and environmental managers.

The insights gained from this research underscore the importance of incorporating environmental considerations into urban planning strategies. The significant relationship between UHI and factors such as population density and land use changes calls for a proactive approach in managing urban heat. The findings advocate for increased vegetation and green infrastructure in urban settings, particularly in areas identified as heat islands.

Urban planning efforts should also consider zoning regulations that promote sustainable land use and minimize impervious surfaces, which contribute to increased heat retention. These recommendations resonate with the work of Han et al. (2023), who emphasized the role of comprehensive urban planning in mitigating UHI effects.

While this study provides valuable insights, it is essential to acknowledge certain limitations. The reliance on satellite imagery, while effective, may not capture microclimatic variations within urban areas. Future research could benefit from integrating ground-based temperature measurements with satellite data to enhance the accuracy of UHI assessments. Additionally, investigating the temporal dynamics of UHI effects over longer periods would offer a more comprehensive understanding of how these phenomena evolve with urban development.

This study successfully demonstrated the UHI effects in Mashhad and Neishabour through the application of MODIS satellite imagery. The findings affirm the significant role of urbanization, population density, and land use in shaping thermal patterns, while also underscoring the utility of satellite data in urban heat assessments. As cities continue to grow, integrating findings from this research into urban planning practices will be critical in mitigating the adverse impacts of UHI, ultimately fostering healthier urban environments.

5. Conclusion

This study aimed to investigate the Urban Heat Island (UHI) effect in the cities of Mashhad and Neishabour using MODIS satellite imagery. The results demonstrated significant variations in surface temperatures between urban and surrounding areas, highlighting the pronounced impact of urbanization on local climatic conditions. Key findings include:

Temperature Disparities: The analysis revealed substantial differences in daytime and nighttime temperatures, with urban areas exhibiting notably higher daytime temperatures. The geographic features surrounding the cities contributed to localized cooling patterns, particularly in the outskirts of Neishabour.

Influence of Urbanization: The spatial distribution of UHI effects was found to be closely linked to factors such as population density, land use changes, and vegetation cover. Areas with higher urbanization displayed greater temperature disparities, reinforcing the notion that urban development exacerbates heat retention.

Reliability of MODIS Imagery: The utilization of MODIS satellite imagery proved to be an effective method for detecting and quantifying the UHI effect. The data obtained offered reliable insights into surface temperature variations, facilitating a comprehensive analysis of the thermal dynamics in these urban settings.

Based on the findings of this study, the following recommendations are proposed to mitigate the UHI effects in Mashhad and Neishabour:

Enhancing Green Spaces: Urban planners should prioritize the integration of green spaces and vegetation into city landscapes. Increasing tree canopies and parks can help lower surface temperatures and improve overall urban air quality.

Sustainable Urban Design: Implementing zoning regulations that promote sustainable land use practices is essential. This includes minimizing impervious surfaces and encouraging the use of reflective materials in construction to reduce heat absorption.

Public Awareness Campaigns: Educating the community about the causes and effects of UHI can foster public support for initiatives aimed at mitigating urban heat. Community engagement in tree planting and sustainable practices can significantly contribute to local efforts.

Future Research Directions: Further studies should explore the temporal dynamics of UHI effects and incorporate ground-based temperature measurements to complement satellite data. This will enhance the understanding of microclimatic variations and inform more targeted urban interventions.

Policy Integration: Policymakers should consider the findings of this research in urban planning and development strategies. Incorporating UHI mitigation measures into broader environmental policies can lead to more resilient urban environments.

In summary, addressing the UHI effect in Mashhad and Neishabour requires a multifaceted approach that combines urban planning, community engagement, and policy integration. By implementing the recommendations outlined above, these cities can work towards creating healthier, more sustainable urban environments that mitigate the adverse impacts of urban heat islands.

Acknowledgements

We would like to express our sincere gratitude to professors in the department of remote sensing and GIS for their valuable support and assistance throughout the course of this research.

Declarations

Funding Information (Private funding by authors)

Conflict of Interest /Competing interests (None)

Availability of Data and Material (Data are available when requested)

Consent to Publish (Authors consent to publishing)

Authors Contributions (Authors contributed equally to the data collection, analysis, and interpretation. All authors critically reviewed, refined, and approved the manuscript.)

Code availability (Not applicable)

REFERENCES

Bighi, M. M., Ashraf, B., Hosseini, A. F., & Mianabadi, A. (2012). Investigate of heat island of mashhad using satellite images and fractal theory. *Journal of Geography and Environmental Hazards*, *1*, 35-49.

Boakye, O. F., Keneshia, H., & Jorge, G. C. (2024). Extreme Heat in the Caribbean: Impacts on Wellbeing and Buildings Energy Infrastructure—The 2023 Summer Case. *ASME Journal of Engineering for Sustainable Buildings and Cities*, *5*(3). https://doi.org/10.1115/1.4066382

Bokaie, M., Shamsipour, A., Khatibi, P., & Hosseini, A. (2019). Seasonal monitoring of urban heat island using multi-temporal Landsat and MODIS images in Tehran. *International Journal of Urban Sciences*, *23*(2), 269-285. https://doi.org/10.1080/12265934.2018.1548942

Cheela, V. S., John, M., Biswas, W., & Sarker, P. (2021). Combating urban heat island effect—A review of reflective pavements and tree shading strategies. *Buildings*, *11*(3), 93. https://doi.org/10.3390/buildings11030093

Cristóbal, J., Jiménez-Muñoz, J. C., Prakash, A., Mattar, C., Skoković, D., & Sobrino, J. A. (2018). An improved single-channel method to retrieve land surface temperature from the Landsat-8 thermal band. *Remote Sensing*, *10*(3), 431. https://doi.org/10.3390/rs10030431

Elsayed, I. S. (2012). Mitigation of the urban heat island of the city of Kuala Lumpur, Malaysia. *Middle-East Journal of Scientific Research*, *11*(11), 1602-1613.

Fu, J., Dupre, K., Tavares, S., King, D., & Banhalmi-Zakar, Z. (2022). Optimized greenery configuration to mitigate urban heat: A decade systematic review. *Frontiers of Architectural Research*, *11*(3), 466-491. https://doi.org/10.1016/j.foar.2021.12.005

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote sensing of Environment*, *202*, 18-27. https://doi.org/10.1016/j.rse.2017.06.031

Han, D., Zhang, T., Qin, Y., Tan, Y., & Liu, J. (2023). A comparative review on the mitigation strategies of urban heat island (UHI): a pathway for sustainable urban development. *Climate and Development*, *15*(5), 379-403. https://doi.org/10.1080/17565529.2022.2092051

Huang, K., Li, X., Liu, X., & Seto, K. C. (2019). Projecting global urban land expansion and heat island intensification through 2050. *Environmental Research Letters*, *14*(11), 114037 DOI 10.1088/1748-9326/ab4b71

Jafari, E., Soltanifard, H., Aliabadi, K., & Karachi, H. (2017). Assessment of the effect of Neyshabur green spatial configuration on the temperature of land surface and heat islands. *Open Journal of Ecology*, *7*(9), 554-567. https://doi.org/10.4236/oje.2017.79037

Kumar, D., & Shekhar, S. (2015). Statistical analysis of land surface temperature–vegetation indexes relationship through thermal remote sensing. *Ecotoxicology and environmental safety*, *121*, 39-44 https://doi.org/10.1016/j.ecoenv.2015.07.004

Naserikia, M., Asadi Shamsabadi, E., Rafieian, M., & Leal Filho, W. (2019). The urban heat island in an urban context: A case study of Mashhad, Iran. *International journal of environmental research and public health*, *16*(3), 313. https://doi.org/10.3390/ijerph16030313

Phan, V. H., Pham, D. P. H., Pham, T. V., Qureshi, K. N., & Pham-Quoc, C. (2023). An IoT System and MODIS Images Enable Smart Environmental Management for Mekong Delta. *Future Internet*, *15*(7), 245. https://doi.org/10.3390/fi15070245

Phan, T. N., & Kappas, M. (2018). Application of MODIS land surface temperature data: a systematic literature review and analysis. *Journal of Applied Remote Sensing*, *12*(4), 041501-041501 https://doi.org/10.1117/1.JRS.12.041501

Rabiei-Dastjerdi, H., Zarghani, S. H., Azami, H., Heydari, A., Janparvar, M., & Jafari, F. (2021). Spatial distribution of regional infrastructures in the northeast of Iran using GIS and Mic Mac observation (A case of Khorasan Razavi province). *Heliyon*, *7*(6).

Sadeghinia, A., Alijani, B., & Zeaieanfirouzabadi, P. (2013). Analysis of spatial-temporal structure of the urban heat island in Tehran through remote sensing and geographical information system. *Journal of Geography and Environmental hazards*, *1*(4), 1-17. https://doi.org/10.22067/geo.v1i4.16950

Singh, N., Singh, S., & Mall, R. K. (2020). Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus. In *Urban ecology* (pp. 317-334). Elsevier. https://doi.org/10.1016/B978-0-12-820730-7.00017-3

Wang, Z., Meng, Q., Allam, M., Hu, D., Zhang, L., & Menenti, M. (2021). Environmental and anthropogenic drivers of surface urban heat island intensity: A case-study in the Yangtze River Delta, China. *Ecological Indicators*, *128*, 107845. https://doi.org/10.1016/j.ecolind.2021.107845

Yang, P., Ren, G., & Hou, W. (2019). Impact of daytime precipitation duration on urban heat island intensity over Beijing city. *Urban climate*, *28*, 100463. https://doi.org/10.1016/j.uclim.2019.100463

Zhou, X., & Chen, H. (2018). Impact of urbanization-related land use land cover changes and urban morphology changes on the urban heat island phenomenon. *Science of the Total Environment*, *635*, 1467-1476.

Zhou, D., Xiao, J., Bonafoni, S., Berger, C., Deilami, K., Zhou, Y., ... & Sobrino, J. A. (2018). Satellite remote sensing of surface urban heat islands: Progress, challenges, and perspectives. *Remote Sensing*, *11*(1), 48. https://doi.org/10.3390/rs11010048